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EXPERIMENTS WITH FERTILIZERS ON COCONUT PALMS AND VARIATION IN PALM PRODUCTIVITY

BY

T. B. McCLELLAND
Director

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EXPERIMENTS WITH FERTILIZERS ON COCONUT PALMS AND VARIATION IN PALM PRODUCTIVITY

By T. B. McClelland, *Director*[1]

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Coconuts valued at approximately $700,000 were annually exported from Porto Rico before the hurricane of September 13, 1928. The storm destroyed many palms, but their loss is expected to constitute only a temporary drawback to the local development of the coconut industry. Most of the coast of Porto Rico is fringed with coconut palms. The area in this crop varies greatly in width but is generally rather narrow. The soils range from beach sand to sandy loam and are probably more uniform in texture than are those planted with most of the other kinds of crops.

FERTILIZER EXPERIMENTS

Cooperative fertilizer experiments on coconut palms were begun in 1912 in Porto Rico by C. F. Kinman, former horticulturist of the station, and were continued by him until his transfer to the mainland in 1918. Since then they have been conducted under the direction of the writer. All field work was terminated by the hurricane of September, 1928, which destroyed nearly two-thirds of the palms in the two groups then under test.

The experiments were made on three plantations in different localities. The palms in each locality were in a different stage of development, and each group represented a distinct period in the life of

[1] The author gratefully acknowledges his indebtedness to A. J. Harvey, the Guanica Centrale, the German Kali Works, Cesar de Chudens, José González, S. V. L. Lippitt, and William Whittemore, whose kindly cooperation made the experiments possible.

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the tree. At San José fertilizer treatment was begun less than two years after the date of planting the nuts, and production of the palms was recorded during the first 15 years. At Corsica the palms were about 16 years old at the time they received the first fertilizer application, and production was recorded for approximately seven years. At Boquillas the palms were decidedly older than those at Corsica, and production was recorded for more than 11 years. Individual production records of nearly 500 palms over a period of years have yielded data which are important not alone as showing production following the application of certain fertilizers, but for what is of broader value, information as to the bearing habits of the coconut palm. This bulletin gives the results of the observations and contains information that should be of value wherever the coconut is grown.

SAN JOSE PLANTATION

The San José plantation of the Harvey brothers is located near the coast and a few miles east of San Juan. The soil is a sandy loam and apparently of uniform texture in the area selected for the fertilizer tests. Late in the fall of 1913 unsprouted nuts were set in this plantation in carefully alined rows 33 feet apart each way. For treatment the trees were grouped in 1915 in nine plats of parallel rows of 10 palms each. No guard rows were left between the plats, as it was originally intended to continue the experiment for only a limited time after the palms should come into bearing.

TREATMENT

Table 1 shows the treatment given the different plats.

TABLE 1.—*Fertilizer treatments, yield of coconuts, and distribution among the plats of the 25 least and the 25 most productive palms, at San José*[1]

Plat No.	Fertilizer applied semiannually from July, 1915, to January, 1926	Average production of nuts per palm in—										Distribution among the plats of the—	
		1920	1921	1922	1923	1924	1925	1926	1927	1928 (half year)	1920–1928	25 least productive palms	25 most productive palms
		No.	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*
1	Salt (NaCl)	13	45	69	74	90	70	68	75	39	544	2	6
2	Nitrogen and phosphoric acid	5	41	64	84	95	72	82	72	43	558	1	4
3	Nitrogen and potash	7	36	64	78	76	53	67	54	29	465	2	3
4	Phosphoric acid and potash	3	19	44	73	70	47	64	57	27	403	5	1
5	No fertilizer	1	11	36	60	56	45	57	52	35	352	7	0
6	Nitrogen; phosphoric acid; and potash	4	31	67	73	75	56	71	65	30	472	1	3
7	Nitrogen; phosphoric acid; and potash (in double quantity)	1	32	66	68	80	59	76	59	34	474	3	4
8	Cow manure supplemented with phosphoric acid and potash	3	20	42	59	66	51	68	59	41	407	4	2
9	Tobacco stems supplemented with nitrogen and phosphoric acid	8	38	51	67	76	55	74	66	42	477	0	2
1–9	Average or total	5	30	56	70	76	56	69	62	35	460	25	25

[1] A single palm was lost during the course of the experiments (palm No. 28 from plat No. 2). As this loss occurred after less than two years of production, the palm has not been included in the totals and the averages. The full-time averages are not identical with the sums of annual averages on account of the fractions added to or deducted from the latter .

The basal fertilizer formula used in plats Nos. 2, 3, 4, 6, and 7 from July, 1915, to July, 1919, was 6 per cent nitrogen, 8 per cent phosphoric acid, and 4 per cent potash. In January, 1920, the percentage of potash was increased to 12 for that and subsequent applications. The fertilizers applied to plats Nos. 2, 3, and 4 were the same in amount of each of two elements as was given plat No. 6, but lacked one element which plat No. 6 received. Plat No. 6 received the standard amount of complete fertilizer. Plat No. 7 received the same kind of fertilizer as plat No. 6, but in double portion. Applications were made semiannually, beginning with a standard rate of 2 pounds per palm at the first application in July, 1915. Subsequent rates per palm per application were 1½ pounds in 1916, 2 pounds in 1917, 2½ pounds in 1918, 3 pounds in 1919, 4 pounds in 1920, and 5 pounds thereafter. The final application was made in January, 1926. Plats Nos. 8 and 9 were fertilized with cow manure and tobacco stems, respectively, supplemented with mineral fertilizers to make the total application of nitrogen, phosphoric acid, and potash comparable to that given plat No. 6. Since both cow manure and tobacco stems show decided variability in analyses the applications were only approximately equivalent, and prior to 1920 it is considered that plat No. 8 received slightly less nitrogen and more potash than were contained in the standard application given plat No. 6. When the fertilizer applications were given in full amount in 1921 and later, plat No. 8 received at each application 600 pounds of manure, 11⅞ pounds of superphosphate, and 6 pounds of potassium sulphate, and plat No. 9 received 100 pounds of tobacco stems, 2½ pounds of ammonium sulphate, and 21¼ pounds of superphosphate. Plat No. 1 received salt (NaCl) alone. Until 1920 the applications of salt equaled in weight the standard fertilizer application. Thereafter the amounts per palm per application were 3 pounds in 1920, 3½ pounds in 1921 and in 1922, and 4 pounds in 1923 and later.

The fertilizer was broadcast more or less over the area overhung by the leaves. Beginning in 1921, deep furrows were plowed between plats prior to applying fertilizer to cut the encroaching roots of palms in adjacent plats. In May, 1926, the fertilizer treatments outlined above having been discontinued, new plats were established crossing the original plats at right angles, and salt was applied to the four palms centrally located in respect to each of the original plats. The salt was broadcast at the rate of 5 pounds per palm, and the application extended as far as the guard row on both sides. The application was repeated in November, 1926, in May and November, 1927, and in May, 1928. The four palms, the two at either end of each of the original plats, which remained untreated, constituted the check in the new alinement. The applications of salt were made for so brief a period prior to the termination of the record that the effect on nut production could have been only slight. Moreover, since all the original plats fared alike in the new treatment, the production records will first be considered without regard to the later salting. Beginning in August, 1927, the field was heavily pastured. Since the last harvest from these palms was in June, 1928, the manure received through the pasturing presumably had no effect on recorded production.

NUT PRODUCTION

In vigorously growing young trees the crown is much less compact than in older trees, and the bunches of nuts are much less securely supported. Consequently, in the early fruiting period of a tree numerous well-developed nuts drop before reaching maturity. No distinction is made here between nuts that drop prematurely and nuts that mature before they are picked, because the production tendency rather than the actual number of salable nuts produced is the main point of interest.

Prior to the beginning of production the thrifty appearance of the palms in plat No. 1, receiving salt alone, was noted.

By January, 1920, six years after planting was done, 10 of 90 palms had blossomed and 25 had flower buds. Six months later, 47 palms had blossomed and 3 additional palms were budded. At that time 10 palms, or all in plat No. 9, and 9 palms in Plat No. 1 had blossomed. In each of the other fertilized plats 4 to 6 palms had blossomed or were budded, whereas in the check plat only 2 had blossomed and none of the others showed buds. This appeared to indicate that fertilization tended to bring the palms into production slightly earlier than would have been the case with unfertilized palms. By January, 1921, all palms had blossomed but one, and it blossomed prior to July, 1921. The average production per palm by plats is given in Table 1.

All treated plats exceeded the check plat in yield, apparently indicating that some benefit had been derived from the materials applied. This assumption is further borne out by the preponderance of low producers among the palms of the check plat and the fact that it included none of the high producers. The rank of the highest-yielding palm in this plat was thirty-fifth from the top.

From a hasty glance at Table 1 it might be inferred that since plat No. 2 gave the highest production, the application of nitrogen and phosphoric acid was the most effective of the treatments used. But plat No. 6, which received the same amounts of nitrogen and phosphoric acid as plat No. 2 and potash in addition produced much less than plat No. 2. Plat No. 7, which received twice the quantity of the same fertilizers as plat No. 6, produced annually only one-fourth nut more per palm than did plat No. 6, and included three palms of low yield, whereas plat No. 6 included but one. Plat No. 1, to which neither nitrogen nor phosphoric acid was applied, produced almost as many nuts as plat No. 2, and more than any of the other four plats to which nitrogen and phosphoric acid in one form or another were applied, and contained more palms of high yield than any other plat. Clearly the wide variation in production was not correlated principally with the application of any one, two, or three fertilizing elements, but was due in a greater degree to some factor more potent than the fertilizers applied.

Figure 1 shows graphically the individual production of the palms as they stood in the field. The differences in production between palms which received identical treatment and which were growing in apparently uniform soil were very pronounced. Palms Nos. 23 and 33 with those on both sides of them furnish notable examples. It is also worthy of note that the most productive palm in the field, No. 23, stood adjacent to, and within 33 feet of the least productive palm, No. 33. The removal of these two palms from their respective plats would have very materially altered the plat averages, and as a result, plats Nos. 1 and 2 would have interchanged positions in rank, and plat No. 3 would have been moved from sixth to third place. These changes, however, would not have simplified greatly the explanation of production in relation to fertilization, with two incompletely fertilized plats outranking the two completely fertilized plats, and the salted plat outranking all others.

Figure 2 shows the curves of individual annual production for the period 1920–1927, and of the 10 most and the 10 least productive palms. At no time did the curves of production of the palms of the two great groups cross. Only 3 of 76 individual annual harvests from the high-production group fell below the average of the field for the respective year, and in no instance did a palm from the low-production group attain average production. Seasonal influence produced variation in yield between one year and another. But in this variation the tendency toward high or toward low production remained clearly evident and consistent. High yielders remained high yielders and low yielders remained low yielders. The total production, including that of the half year 1928, of the one group was 7,242 nuts, and that of the other was 2,415 nuts, which was a ratio of 3 to 1. Still another difference between the groups was the earlier maturity of the more productive palms. Six of the ten high-producing palms yielded nuts in 1920, and the other 4 did so the following year, whereas none of the 10 low-producing palms fruited in 1920, and 3 failed to fruit prior to 1922.

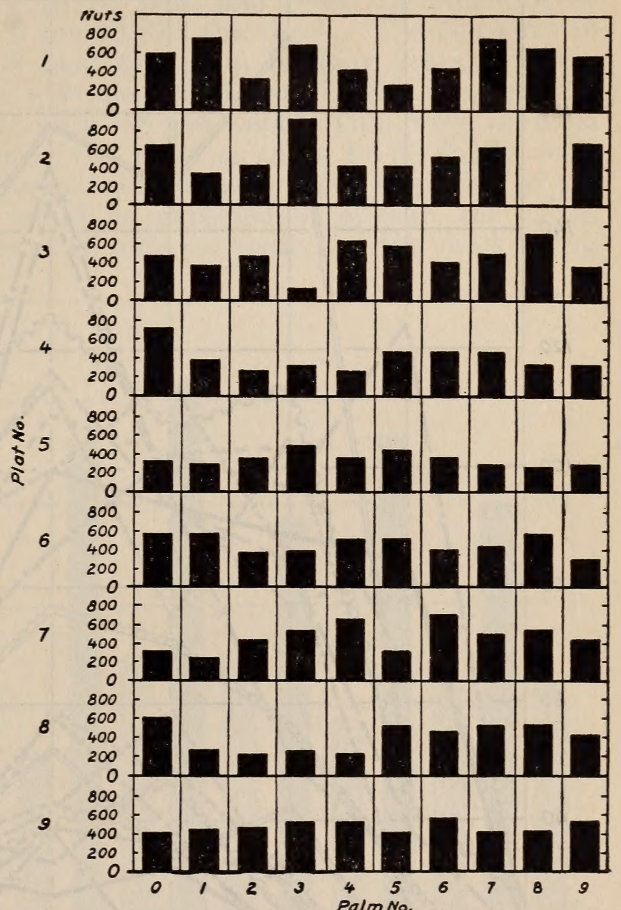

FIGURE 1.—Nut production by individual palms, San José plantation, 1920–1928. Relative position as in the field. To find the palm number, combine the ten's place and the unit's place numbers. Thus, the palm in the upper left corner is No. 10, that in the upper right corner No. 19, that in the lower left corner is No. 90, that in the lower right corner No. 99, while the missing palm indicated by a blank is No. 28

For further comparison of high and low producers, two larger groups were considered, consisting, respectively, of the 25 palms which gave the highest and the 25 which gave the lowest total production. Each group thus consisted of slightly more than one-quarter of the palms in the experimental plats. The yields of the two groups were 15,991 and 7,318 nuts, respectively. One group yielded more than twice as many nuts as did the other. In other words, the average palm in one group was worth two palms in the

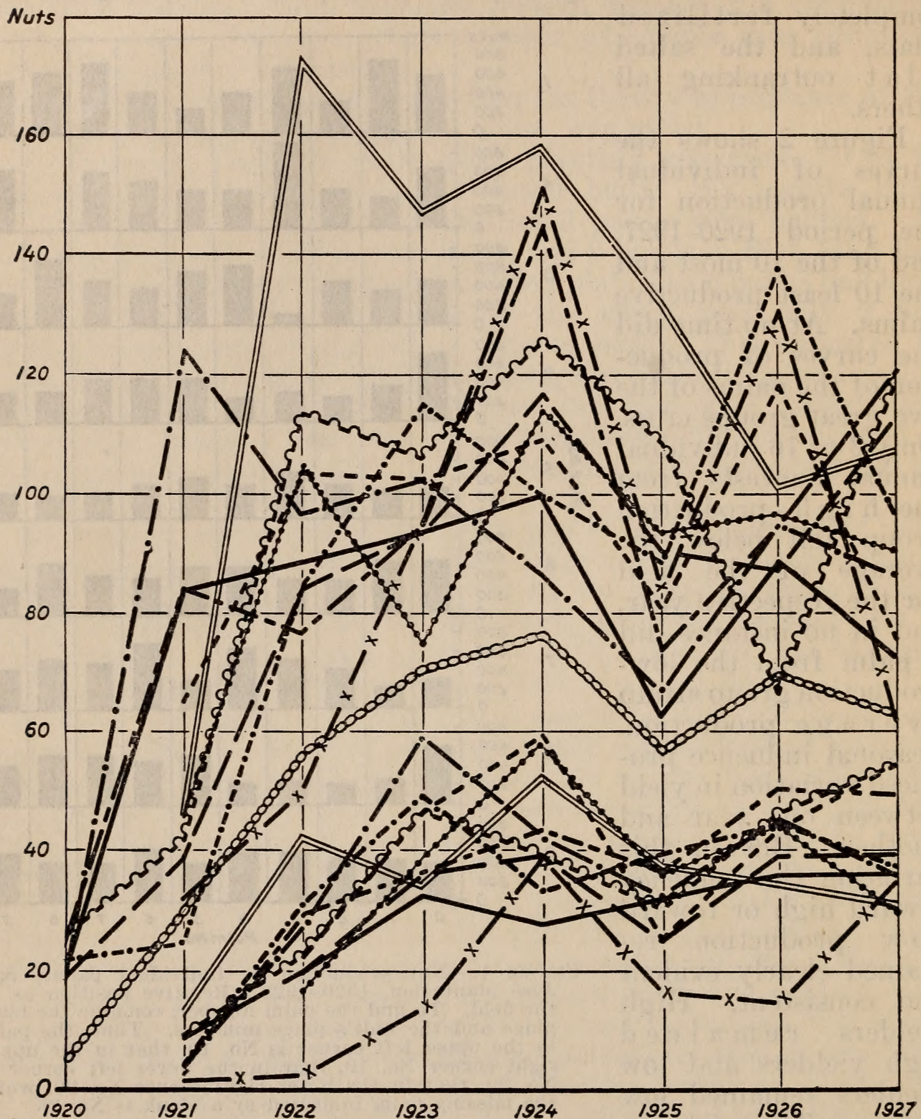

FIGURE 2.—Individual annual production 1920–1927 San José plantation, of the 10 most productive and of the 10 least productive palms. The chain shows the average production for the field

other. Their annual productions for the period 1920–1927 are contrasted in Figure 3. The superiority of the one group over the other was constant rather than intermittent and was particularly pronounced in the early years of production. As in the smaller groups already considered, the early maturity of the palms which later proved to be high yielders was a notable characteristic. In

1920, in the high-production group 17 of 25 palms came into production, whereas in the low-production group only 5 of 25 palms did so. In 1921 all palms in the former group fruited, whereas in the latter group seven palms did not fruit until the following year.

As has been stated, the original plats were crossed at right angles by new plats beginning in May, 1926, to test the effect of salt on yield of nuts. The palms which bore the numerals 3, 4, 5, or 6 in unit's place constituted the salted plat, and those the numerals of which ended in 0, 1, 8, or 9 constituted the check. The 36 palms in the former averaged 262.8 nuts per palm in four years, whereas the 35 palms in the latter averaged 260.8 nuts in the same period, which was a difference of only 0.8 per cent. This very uniform average production indicated the plats as units to be fairly comparable. In 1927, the earliest possible date at which any effect of the treatment on production could be expected to appear, the salted palms produced an average of 63 nuts per palm and the check palms

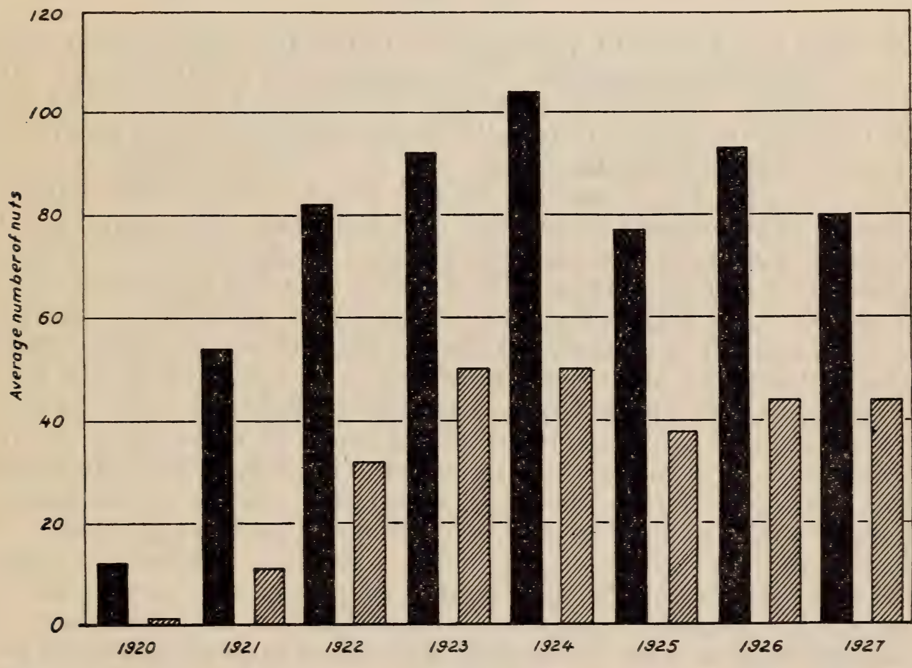

FIGURE 3.—Average nut production per palm, San José plantation, 1920–1927, of the 25 most productive and of the 25 least productive palms, the former in solid, the latter in shaded blocks

61.9. In comparison with the yields of the preceding year these were reductions of 5.5 and 11 nuts per palm, respectively. In the half year 1928, during which the yields were recorded, the salted palms averaged 37.3 nuts per palm, whereas the check palms averaged 32.9 nuts, which was a difference of 4.4 nuts, or 13.4 per cent in favor of the salted palms. Unfortunately, the hurricane terminated the experiment in September, 1928. In the brief duration of the experiment the recorded production indicated a possible benefit from the application of salt, but the period was too brief to warrant drawing conclusions.

CORSICA PLANTATION

In 1922 a fertilizer experiment with coconut palms was begun at Corsica, P. R., on a plantation owned at the time by Cesar de Chudens and later by José González. The plantation was chosen because the palms there were mature though not very old, evidently not in maximum production although in fair condition, and as uniform as were to be found in that locality. The palms were said to be about 16 years old. They were growing in a sandy loam, typical of that usually planted with coconuts. The palms were in rows in one direction only, the spacing in the rows not being uniform. The average spacing was about 33 feet. The older coconut plantations were made with little regard to spacing or alinement. In some of the plantings no rows are to be seen, the palms being scattered here and there apparently without order or system, and in other plantings the palms are somewhat more orderly through alinement in a single direction.

TREATMENT

A block of 14 rows of palms was selected for the fertilizer tests. It was divided into five plats of two rows each, leaving guard rows between plats. Each plat contained 20 palms. Owing to the fact that the rows of palms ran parallel to the water front, the plats were unequally distant from the beach, plat No. 1 being farthest removed from, and plat No. 5 nearest to, the water front, about 200 feet distant. It is common knowledge that the beach offers particularly favorable conditions for coconut palms. In order that a possibly higher yield resulting from advantageous location might not be attributed to fertilization, the plat nearest to the beach was selected as the check and left untreated. Although this did not constitute a satisfactory check, the arrangement seemed to be advisable at the time.

Fertilizers were applied twice annually from March, 1922, to July, 1928, making 14 applications in all. Except on three occasions the applications were made in January and in July. Each fertilized palm, plats Nos. 1 to 4, inclusive, received 2 pounds of ammonium sulphate and 2 pounds of superphosphate at each application. In addition to this, each palm in plat No. 2 received 2 pounds of potassium sulphate, in plat No. 3, 2 pounds of potassium chloride, and in plat No. 4, 1 pound 9 ounces of sodium chloride. The fertilizer was broadcast over an area inclosed by a circle of approximately 18 feet in diameter with the palm in the center and lightly hoed in. The palms in plat No. 5 received no fertilizer.

NUT PRODUCTION

Two palms died during the course of the experiment, and their production is not included in the record. The experiment was terminated by the hurricane of September, 1928, which left standing only 32 of 98 palms.

The nuts were collected thirty times during the course of the experiment. On two occasions a laborer removed some nuts prior to recording production, thus necessitating the elimination of these two harvests from the comparative record. The nuts mature throughout the year, and a division of production into calendar years gives an accurate idea of the distribution of production only when the collections are made at brief or regular intervals. Collections were at somewhat variable intervals. Since an average interval of two and three-fourths months elapsed between pickings, there were four collections in some calendar years and five in others. For an analysis of the effect of fertilization on production, the harvests were divided into three periods, the first of 8, the second of 12, and the third of 8 harvests. This arrangement placed one of the eliminated harvests between the first and second periods and the other within the second period. The first period extended from January, 1922, to August,

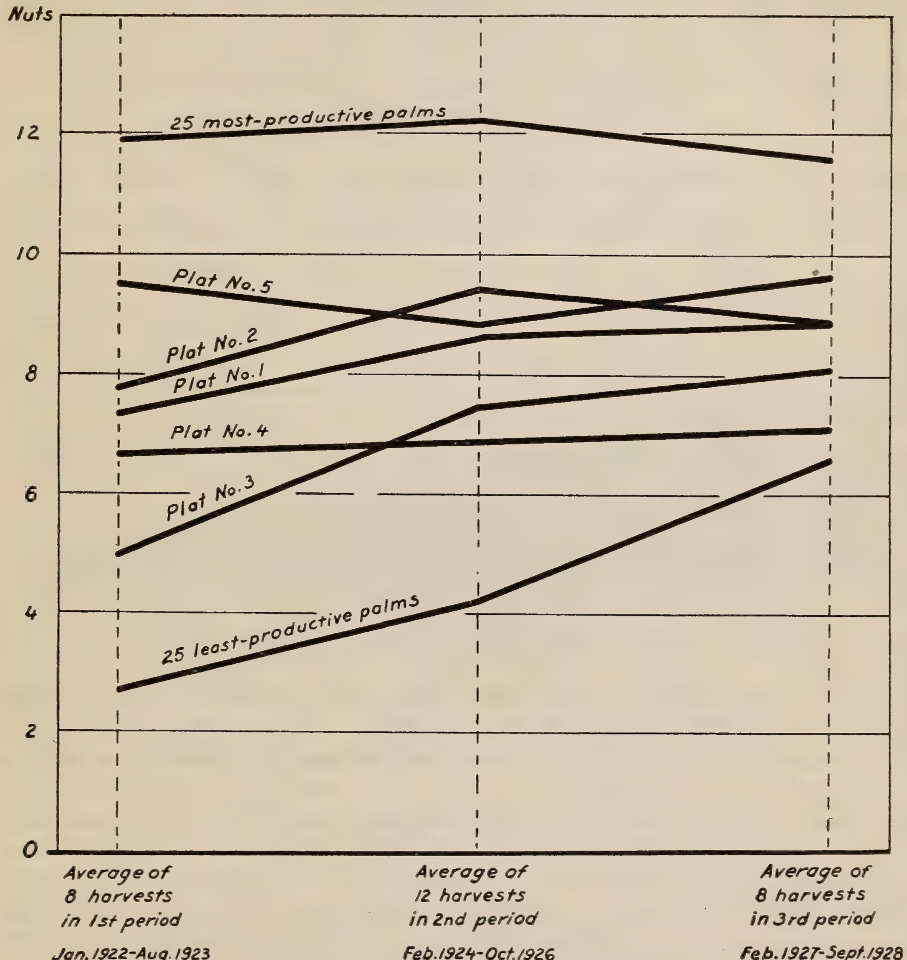

FIGURE 4.—Production per palm per picking at Corsica plantation

1923, and the last period from February, 1927, to September, 1928, the seasonal range of the two periods being much the same.

Since the first fertilizer application was in March, 1922, 17 months prior to the end of the first period, and since a coconut requires a year in which to mature, very little, if any, effect of the fertilizer would be expected to show in an increased number of nuts produced during the first period. The production during this period was used accordingly as a check on subsequent production.

Figure 4 shows the production for the three periods, in nuts per palm per picking for each plat and for the 25 palms which gave the lowest and the highest yields, respectively, throughout the course of the experiment.

Of the five plats, No. 3 showed the greatest increase in yield. The four fertilized plats differed only in regard to potash, its omission, form, or replacement by sodium. If the notable increase in yield of plat No. 3 were due to the application of potassium chloride, an increase in yield would be expected to follow either the application of potash in the form of potassium sulphate in plat No. 2 or the application of chlorine in the form of sodium chloride in plat No. 4. A comparison of the total yield during the second and third periods with that of the first period shows that plat No. 1, receiving no potash, made practically the same increase in yield as plat No. 2, which received potassium sulphate. Certainly no benefit appeared to have resulted in plat No. 2 from the application of potash. The ratios of total production of first period to that of combined second and third periods were as 1 to 2.926 for plat No. 1 and 1 to 2.922 for plat No. 2, which is a difference of less than one-half of 1 per cent. The ratio for plat No. 4, which received sodium chloride, was 1 to 2.62. This plat showed very little increase in yield throughout the duration of the experiment and gave the lowest yield of any plat in the second and third periods. Since in the experiments at the San José plantation the second highest production was from the plat which received sodium chloride alone, it would be unreasonable to attribute the poor production of plat No. 4 to the application of sodium chloride. In view of these contradictory results it would be illogical to ascribe the increase in yield in plat No. 3 to the application of potassium chloride.

The unfertilized plat gave the highest yield of any in both first and third periods, but was surpassed by one plat in the second period. The production of the second and third periods as a unit showed a slight decline for the check and an increase for all fertilized plats. That a wide variation existed between the individuals comprised in a plat is shown by dividing the plats into north and south halves and considering each half plat as a unit. A comparison of the yield of the last with that of the first period shows that the north half of plat No. 1 decreased 10 per cent, whereas the south half increased 75 per cent. In like manner, the halves of plat No. 2 showed increases of 4 and 22 per cent, respectively; plat No. 3, increases of 60 and 67 per cent; plat No. 4, a decrease of 11 per cent in the north half and an increase of 30 per cent in the south half; and plat No. 5, an increase of 5 per cent in the north half and a decrease of 4 per cent in the south half. Thus, a group of 9 or 10 palms receiving the same fertilizer treatment as a second group of 9 or 10 palms responded very differently from the latter in most of the comparisons. These inconsistencies are such as to indicate the presence of a potent factor or factors veiling the effects of the fertilizers. If the difference in yield between the first and last periods be calculated on an annual basis, it is seen that the increase per palm was 6.2 nuts for plat No. 1, 4.4 nuts for plat No. 2, 13.8 nuts for plat No. 3, 1.8 nuts for plat No. 4, and 0.4 nut for plat No. 5. An average annual increase of less than 7 nuts per palm followed annual applications of 8 to 12 pounds of high-grade fertilizer costing from 15 to 25 cents at the local fertilizer agencies. An additional cost of 5 cents may be added for transporting, mixing, and applying the fertilizer, which would bring the total cost to between 20 and 30 cents per palm. If the production of the first period is taken as the normal production, an assumption fairly well supported by the subsequent record of the check, the increase in production following fertilization was insufficient to cover the expenditure involved except with abnormally high prices prevailing for coconuts.

The variation in total number of nuts produced per palm in the course of the experiments is shown diagrammatically in Figure 5. The 20 lowest yielders among the palms produced 2,161 nuts, in contrast with a production of 6,938 nuts by the 20 highest yielders. For every nut produced by the former, 3.2 nuts were produced by the latter. Although the palms occupied the same area of land, those in one fifth of the whole area were worth more than three times as much as those in another fifth.

The 25 lowest yielders, or one-quarter of the number included in the experiment, produced 2,930 nuts, whereas the 25 highest yielders produced 8,357 nuts. Thus, one quarter of the palms were almost

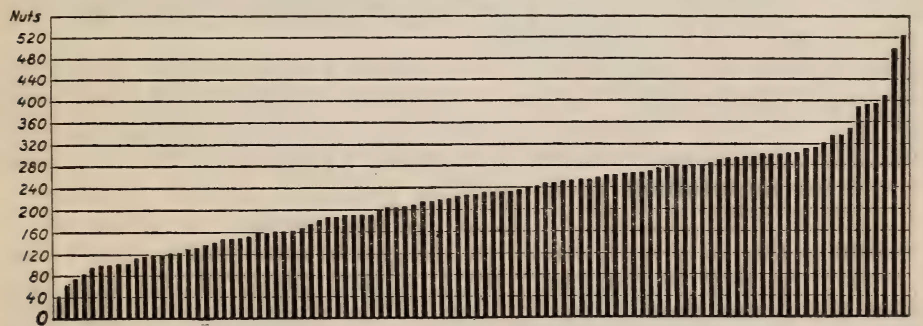

FIGURE 5.—Variation in total nut production per palm, in 20 harvests at Corsica plantation. Each line represents the nuts produced by one palm

three times as valuable as another quarter. Table 2 shows the fertilizer treatments and the distribution in the plats of the 25 lowest and of the 25 highest yielding palms at Corsica.

TABLE 2.—*Fertilizer treatments and distribution among the plats of the least productive and of the most productive palms at Corsica*

Plat No.	Fertilizer applied per palm					Distribution among the plats of the—	
	Ammonium sulphate	Superphosphate	Potassium sulphate	Potassium chloride	Sodium chloride	25 least productive palms	25 most productive palms
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Number*	*Number*
1	2	2	0	0	0	4	5
2	2	2	2	0	0	5	8
3	2	2	0	2	0	5	2
4	2	2	0	0	1$\frac{9}{16}$	7	2
5	0	0	0	0	0	4	8

The distribution of the palms shows in them a tendency to produce much or little, unrelated to the kind of fertilizer applied. Their production by periods is shown in Figure 4. The high yield of the palms in the one group was not due to high production for a brief time. In each of the three periods they gave a high yield. As a whole, their production varied little from one period to another.

Of the 25 palms in the high-yielding group, 8 received no fertilizer and 17 received fertilizer. Of the 8 unfertilized palms, 5 gave a higher production per picking in the first than in either the second or the third period, and 3 gave a higher production per picking in both the second and the third periods than in the first period. Of the 17 fertilized palms of this group, 5 produced more per picking in the first period than in either the second or the third period, and 8 produced more in both the second and third periods than in the first period. The remaining 4 palms showed in the second period an opposite trend from that shown in the third period when compared with the first period. If the second and third periods are considered as a unit, the 17 high-yielding fertilized palms will be found to have averaged in this period 11.7 nuts per palm per picking, whereas in the first period the yield was 11 nuts per palm per picking, the average interval between pickings being the same, 2.7 months. These high-yielding palms thus failed to show any pronounced response to fertilization.

Twenty-one of the twenty-five lowest yielders were fertilized. Nineteen of the fertilized palms yielded more in the third than in the first period. The increase in yield under fertilization was pronounced. Notwithstanding the increased production, the low-yielding palms maintained their relative positions as low yielders in comparison with the other palms. When ranked in order of increasing yield, only 1 of the 25 palms got beyond thirty-ninth place in either the first or the last period, a fact which shows that these palms were consistently low yielders. The highest rank held in the first period by any palm of the 13 lowest yielders was twenty-first place, and in the last period only 2 of the 13 ranked higher than twentieth place.

BOQUILLAS PLANTATION

In 1912 a fertilizer experiment was begun in the Boquillas coconut plantation near the coast southwest of Añasco. (Pl. 1.) Both as to palms and soil the area chosen was typical of the average plantation of old palms. The palms were in fairly good alinement and spaced about 27½ feet apart. They were average to tall in height, and evidently had been in production for many years. The soil was slightly rolling sandy loam. The water in a small spring about 6 feet below the surface of the ground between the experimental plats and the ocean was said to be salty in flavor. Analysis of the water by the station chemist showed that it contained practically no salt (sodium chloride), but was heavily charged with calcium bicarbonate. Its chlorine content was less than 0.05 part per million.

TREATMENT

For the work with fertilizers seven parallel plats were set aside, each containing two rows of 24 palms, excepting palms missing or excluded, with guard rows between plats. During the course of the experiment several trees were eliminated on account of bud rot or other cause. Hence, of the 303 palms included in the first period,

FIGURE 1.—COCONUT PLANTATION, BOQUILLAS

FIGURE 2.—COCONUT FERTILIZER PLATS, BOQUILLAS

only 287 palms remained in the last period. The plats thus varied slightly from period to period in number of palms included, ranging in the first period from 41 to 47 palms each and in the last period from 40 to 42 palms each.

The plats were treated at the rate of 5 pounds per palm with a fertilizer combination having as its basal formula 6 per cent nitrogen, 8 per cent phosphoric acid, and 12 per cent potash. Applications were made twice annually from June, 1912, to June, 1916. The fertilizer was broadcast as far as the guard rows. The guard rows received at each side, respectively, the same kind and amount of fertilizer as was given to the adjacent test plat, in order to obviate robbing by the trees in the guard rows. Three plats were given incomplete fertilizer, three were given complete fertilizer, and one received nothing. Of the three plats receiving complete fertilizer, plat No. 6 received double quantity, and in plat No. 7 the nitrogen was carried in dried blood. For all plats except the latter the nitrogen was supplied in ammonium sulphate. The other elements were supplied in superphosphate and in potassium sulphate. After a 5-year interval following the fertilizer applications, salt (sodium chloride) was applied semiannually from July, 1921, to January, 1924, to four plats. Two plats were given 2½ pounds and two were given 5 pounds per palm per application. As was the case in the earlier applications, the salt was broadcast to the guard rows, for which salt was provided at the same rate for the area treated. Table 3 shows the fertilizer treatments.

TABLE 3.—*Fertilizer treatments, yield of coconuts, and distribution among the plats of the 50 least and of the 50 most productive palms, at Boquillas*

Plat No.	Fertilizer applied per palm from June, 1912, to June, 1916				Amount of NaCl per application from July, 1921, to January, 1924	Average yield of nuts per palm during—					Total yield	Distribution among the plats of the—	
	Amount per application	N	P_2O_5	K_2O		First period, July, 1913, to May, 1915	Second period, August, 1915, to June, 1917	Third period, September, 1917, to July, 1919	Fourth period, October, 1919, to June, 1921	Fifth period, October, 1921, to January, 1924		50 least productive palms	50 most productive palms
	Lbs.	*P. ct.*	*P. ct.*	*P. ct.*	*Lbs.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*
1	5	6	0	12	2½	68.7	54.7	[1] 58.7	44.7	33.8	[1] 260.6	9	3
2	5	6	8	0	0	60.9	45.3	60.9	36.7	31.7	235.5	7	9
3	5	0	8	12	5	65.5	51.6	68.3	42.5	32.8	260.7	7	5
4	0	0	0	0	0	71.6	61.8	70.7	46.3	40.9	291.3	5	8
5	5	6	8	12	0	76.3	75.9	71.1	37.9	36.8	298.0	10	11
6	10	6	8	12	5	77.7	80.5	68.8	33.3	33.6	293.9	5	7
7	5	6	8	12	2½	69.8	73.1	65.5	47.3	50.5	306.2	7	10

[1] In the twenty-fourth harvest the record from 5 palms in plat No. 1 was not obtained, the nuts having been removed previous to entry. This fact was disregarded both in these and other calculations. Here it presumably reduced the average by approximately 1 integer.

NUT PRODUCTION

The production of each palm was recorded separately as in the other experiments. The intervals between harvests were not uniform but averaged approximately three months. The first recorded harvest was in February, 1913, and the last in September, 1924. Through accidents the record was unobtainable for certain harvests.

However, between the third harvest in July, 1913, and the forty-fifth harvest in January, 1924, the record was broken by the omission of only three harvests—the twenty-second, the thirty-eighth, and the forty-third.

Figure 6 shows the average production per palm per harvest. The solid line shows the average production if all the palms are included, whereas the broken line shows the production averaged at each harvest for only such palms as contributed to that particular harvest. The curves very closely approximated one another for the first seven years, after which they diverged widely. This dissimilarity in the last four years indicated one or both of two things: Either many palms produced nothing at all or the pickers were unwilling to climb palms which offered only a small return for the labor involved. In either case a diminishing production was shown. The pickers, who receive so much per thousand nuts thrown down, will not climb a tall palm which offers in return for their efforts only one or two mature nuts. The curves show that whereas the

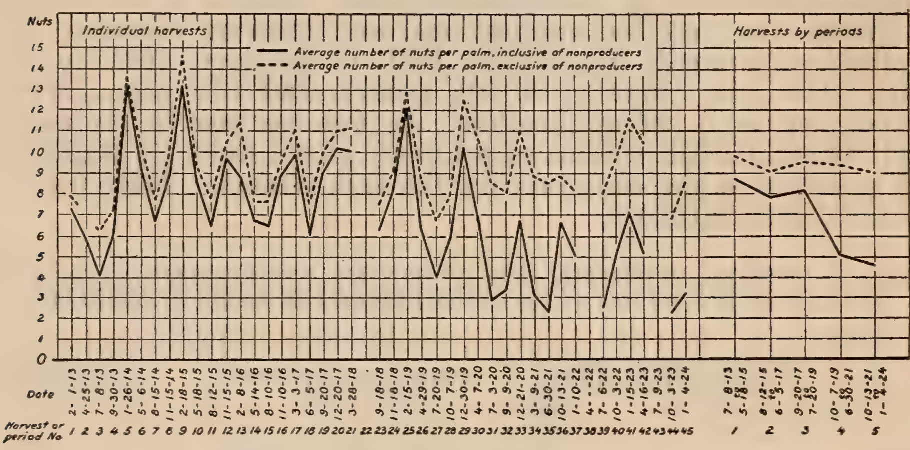

FIGURE 6.—Average yield of nuts per palm in harvests considered both individually and grouped, Boquillas plantation

planter suffered a heavy loss, the pickers did not allow this diminishing production to affect their pro rata receipts from palms climbed, which remained approximately as formerly. Had the pickers been willing to bear a share in the reduction of returns by climbing all the palms bearing mature nuts, the reduction in yield would have been less pronounced, the income to the planter would have been greater, and the record of production as influenced by soil treatment more satisfactory from an experimental point of view.

From the data presented in Figure 6, a seasonal production curve was constructed as is shown in Figure 7, each point being determined by averaging the collections of the preceding and of the following month with those made during each month. This production curve showed that the peak was reached in January and that the smallest production was made in the summer months.

The comparisons of individual and plat yields were based on the 40 harvests recorded between July, 1913, and January, 1924. For purposes of analysis, the harvests were divided into five periods of eight harvests each. The first, second, and fourth periods were unbroken by omitted harvests, whereas one was omitted within the third and two within the fifth period. Figure 6 shows the average production per palm for the plats as a unit for each period, the heavy shading indicating the average when all the palms were included and the light shading when only producing palms were included. The production was fairly uniform for the first three periods, and the average harvest showed only a small proportion of nonproducing palms, whereas this proportion greatly increased in the last two periods.

Since fertilizer applications were begun in June, 1912, and terminated in June, 1916, benefits resulting from the application would be expected to appear during the first or the second period, that is, between July, 1913, and June, 1917. The production of the plats as a unit during the second period, however, was less than that during the first period, and gained slightly during the third period, one to three years after the final application. (Fig. 6.) Production thus

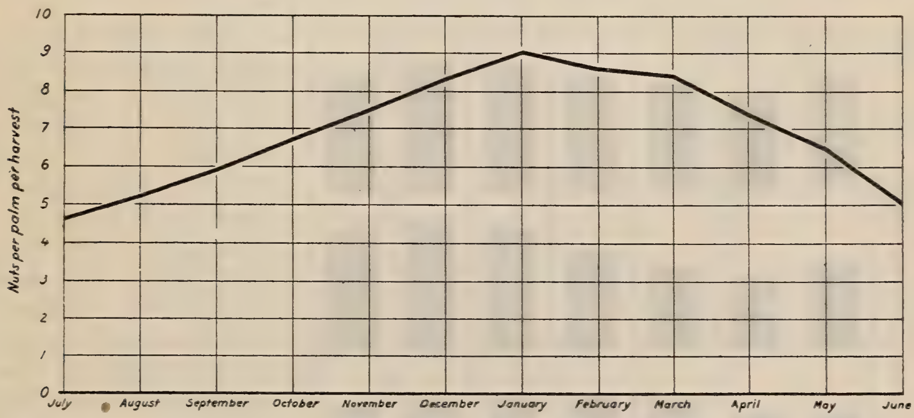

FIGURE 7.—Seasonal production curve for coconuts, as shown by harvest records at Boquillas plantation, 1913 to 1924

failed to indicate any progressive benefit from the fertilizers as a whole.

The yield of each plat for each period is given in Table 3 and is shown graphically in Figure 8. The diagrams of plat yields for the first and second periods closely resemble each other in sequence. If it be assumed that the increased production shown by the three plats which received complete fertilizer was due to the fertilizer, then the conclusion would naturally follow that the three plats each of which received two rather than three fertilizer elements were injured by the fertilizers received, since their production fell short of that of the check by as much as that of the others exceeded it. Since it is clearly incredible that of three fertilizing elements each combination of two should prove to be injurious, whereas the three together should prove to be beneficial, the differences are without particular significance.

A more detailed examination of the production throws light on the situation. If each plat is divided transversely into three sections A, B, and C, containing, respectively, palms Nos. 1 to 8, 9 to 16, and 17 to 24 in double rows, the records of productions for the first and the second period considered separately or together will show an area of high production in the northwest corner of the field comprising section A of plats Nos. 4 and 5 and sections A and B of plats Nos. 6 and 7. The production for the two periods combined is shown diagrammatically in Figure 9 and is given in Table 4.

TABLE 4.—*Average number of nuts produced per palm per subdivided plat in 16 harvests, July, 1913, to June, 1917, at Boquillas plantation*

Plat No.	Nuts in—			Plat No.	Nuts in—		
	Section A	Section B	Section C		Section A	Section B	Section C
	Number	*Number*	*Number*		*Number*	*Number*	*Number*
7	177	150	109	3	128	104	119
6	205	147	126	2	102	91	125
5	230	117	115	1	144	94	138
4	175	125	103				

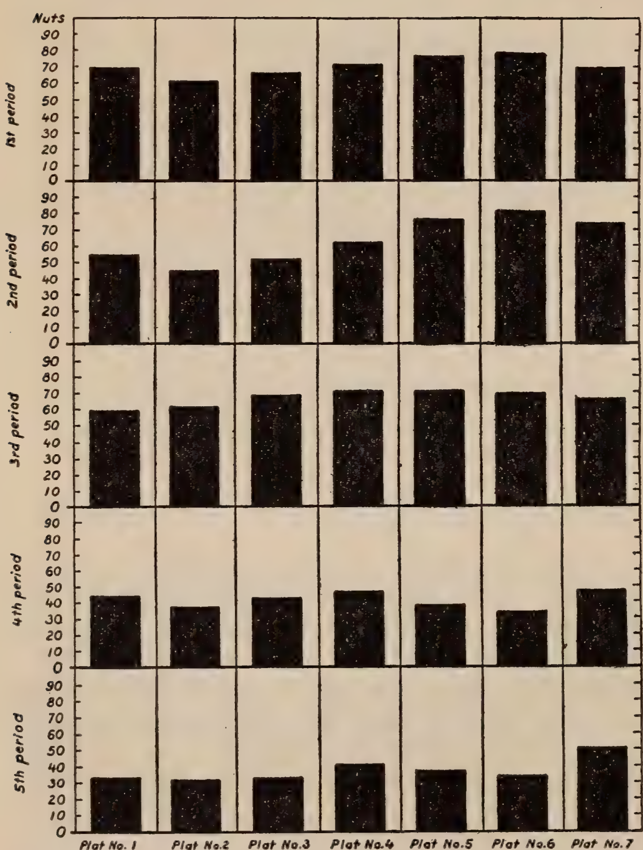

FIGURE 8.—Average yield per period of the different plats, in nuts per palm during five periods of eight harvests each, 1913 to 1924, Boquillas plantation

The record covering the periods during which the effect of the fertilizers should have been most pronounced, that is, from a year after the first to a year after the final application of fertilizers, principally shows decided inequalities in the field that are unrelated to fertilization. Section A of plat No. 5 produced per palm approximately as much as sections B and C of the same plat combined, namely, a production ratio of 2 to 1, although all received equal applications of complete fertilizer. Sections A and B of the check plat, No. 4, in combined yield produced more than any two combinations of fertilized B and C sections. Such inequalities in the field veiled any fertilizer effects which may have been present.

As has already been explained, the record for the fifth period, during which four plats received salt, was less satisfactory than the earlier record. If the inequalities both within and between plats are taken into consideration, a comparison of production in the fifth period with that of the fourth period would appear to be the best criterion for judging the effect of salt on production. Plats Nos. 1 and 7, which received salt at the rate of 2½ pounds per palm per application, yielded in the fifth period at the average rate of 42.2 nuts per palm, whereas in the fourth period the rate was 46 nuts per palm, the yield in the fifth period being only 92 per cent as great as that in the fourth period. Similarly plats Nos. 3 and 6, receiving salt at the rate of 5 pounds per palm per application, produced in the fifth period 33.2 nuts per palm in contrast with 37.9 nuts in the fourth period, the fifth-period yield being 88 per cent as great as that of the fourth period. The average yield of plats Nos. 2, 4, and 5, which received no salt, in the fifth period was 36.5 nuts per palm, which was 91 per cent as great as that of the fourth-period yield of 40.3 nuts per palm. Under the three treatments the production fell in the fifth period to 92, 88, and 91 per cent, respectively, of what it had been in the period preceding, thus in the uniform decline failing to indicate any effect of salt on yield. If comparisons are made of actual numbers of nuts produced, it is seen that the check stood between the treated plats in the fifth period and that the groups remained in the same sequence as before receiving salt.

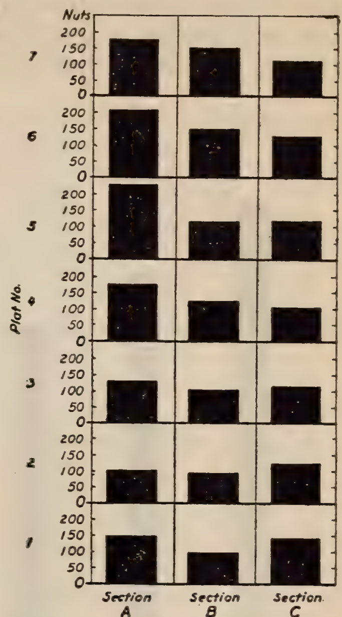

FIGURE 9.—Average number of nuts produced per palm per subdivided plat in 16 harvests, July, 1913, to June, 1917, at Boquillas plantation

The production of 287 palms recorded throughout the five periods is shown graphically in Figure 10. The variation in individual productivity was very great.

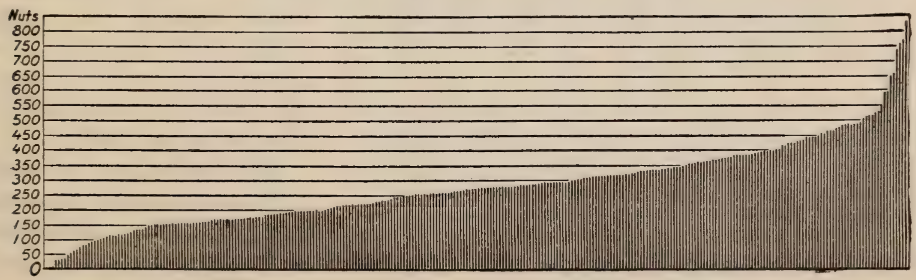

FIGURE 10.—Variation in total nut production per palm in 40 harvests at Boquillas plantation. Each line represents the nuts produced by one palm

Figure 11 contrasts the yield by periods of the 50 most productive palms with that of the 50 least productive palms for the entire time covered by the record and shows that a group of palms which were low or high yielders in one period were respectively low or high yielders in each of the other periods. Whereas the average production of the 50 least productive palms was 106 nuts, that of the 50 most productive was 494.2 nuts, which is a ratio of 1 to 4.7. The distribution of these low and high yielders among the plats is given in Table 3. When it is noted that the check plat No. 4 and the most heavily fertilized plat No. 6 differed only in the check having one additional highly productive palm, and that plat No. 5, a fertilized plat and adjacent to the check, had twice as many low-yielding palms as the latter, no correlation can be seen between fertilization and the number of low or high yielding palms in a plat.

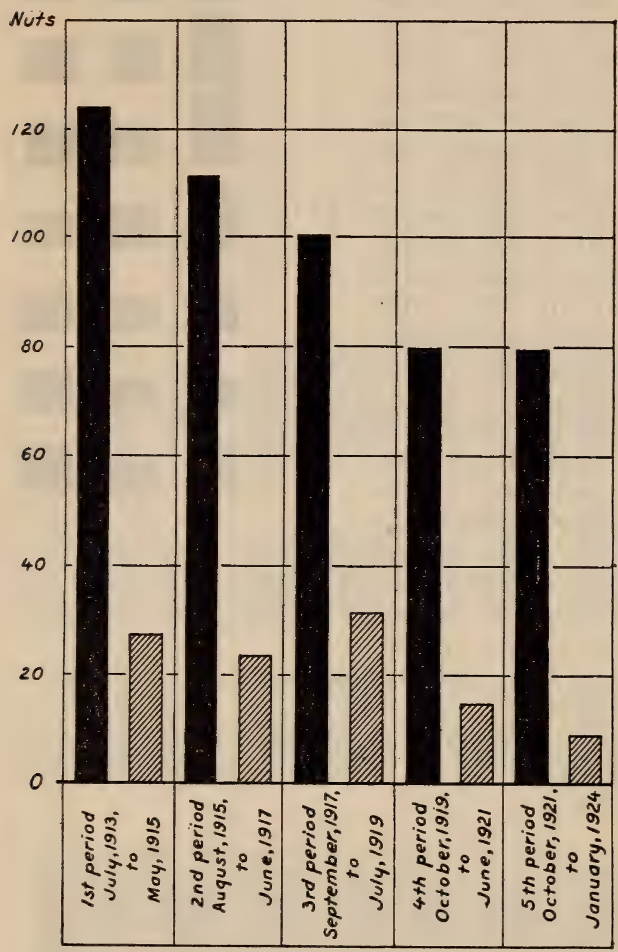

FIGURE 11.—Average nut production per palm, by periods of eight harvests each, of the 50 most productive and of the 50 least productive palms, Boquillas plantation; the former in solid, the latter in shaded blocks

DRAINAGE

As this field is only very slightly above sea level and in places is inclined to be swampy in the rainy season, a survey was made to learn whether or not a correlation existed between production and elevation, in this case the equivalent of drainage. The elevation above sea level [2] was measured to one-tenth inch of a point within several feet of, and approximately on a level with, the base of each palm. The elevations were found to range from 4.2 to 9.2 feet above sea level. Figure 12 shows the elevations diagrammatically.

If the palms in each plat are grouped according to the elevation of each palm and the plats are compared, it is seen that the two plats which had the greatest number of palms at elevations of 7 feet and over, and also the fewest at elevations below 6 feet, were the most productive, whereas the least productive plat had the greatest number of palms at elevations below 6 feet. The average elevation

[2] Sea level was determined May 15, 1926, at 10 a. m. Tide at this hour at Fajardo was 0.85 foot above the datum of mean low water. High tides at 11.15 a. m. and at midnight were 0.95 foot and 1.8 feet, respectively, above mean low water. These data were furnished by R. J. Auld, executive officer, Steamer Ranger, U. S. Coast and Geodetic Survey, who stated also that comparisons had shown that the difference in tidal action between Fajardo and San Juan was negligible. Presumably, the tidal action on the west coast would not be greatly different.

of the 50 most productive palms was 6.9 feet, whereas that of the 50 least productive palms was 5.9 feet. The production of the 303 palms during the first two periods was compared on a basis of elevation. The 131 palms at elevations of less than 6 feet averaged 113.6 nuts per palm, whereas the 114 palms at 6 to 6.9 feet elevation averaged 130.7 nuts and the 58 palms at 7 to 9.2 feet elevation averaged 180.8 nuts. This is shown graphically in Figure 13. Evidently the better drainage afforded by the higher elevations was an important factor in promoting heavier production.

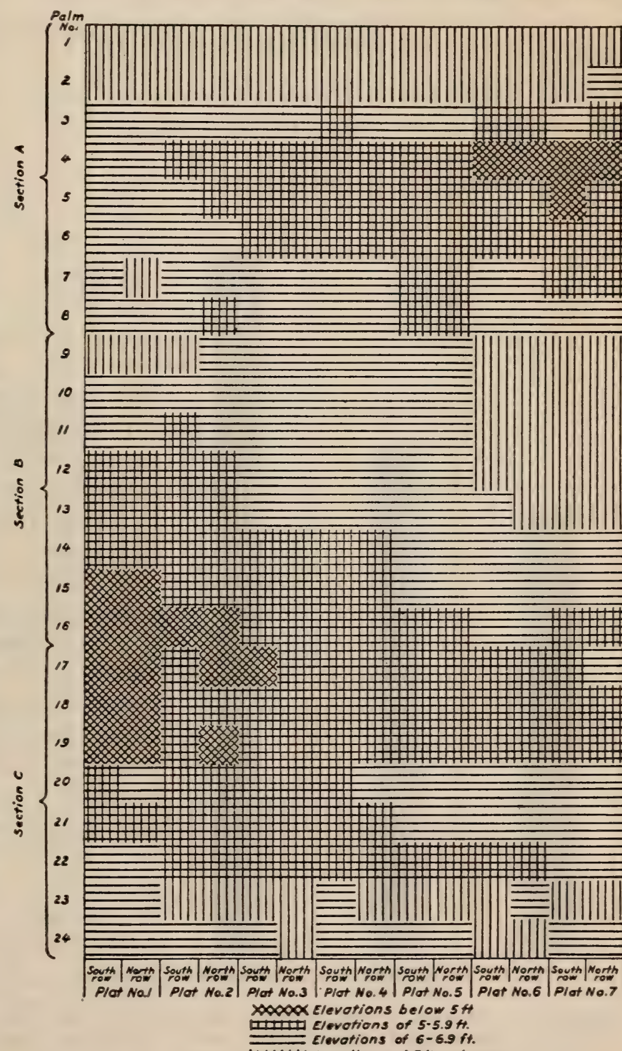

FIGURE 12.—Elevations above sea level in experimental plats, Boquillas plantation

NUT SIZE

The diameters of 100 unselected, intermixed nuts from each plat were measured in each of the first 20 harvests. The minimum, average, and maximum of the 20 average diameters obtained for each plat are given graphically in Figure 14. This graph shows the variation between plats in average nut diameter to have been slight. The greatest difference in minimum measurements between plats was only 0.1 inch and between maximum measurements 0.15 inch, whereas the averages showed an extreme difference in nut diameter of only 0.05 inch, or 1 per cent.

For a more detailed examination for possible effects of fertilizer on nut size, the measurements for the 20 harvests were grouped into four periods of five harvests each. The average nut diameters for the different plats for each period are shown in Figure 15. The size of the average nut in the second 5-harvest period was greater than that in the first similar period in every plat. Since this increase in size occurred in the check as well as in the treated plats, it could not be attributed to fertilization. The third period showed a decrease in size in every plat except the check, followed by an increase in size in five plats in the fourth period. The average nut size in plat No. 3 varied from one period to another by only 0.04 inch. The next smallest difference, 0.06 inch, occurred in both the check plat No. 4 and in the completely fertilized plat No. 5. The greatest difference, 0.18 inch, was in plat No. 1. No correlation was shown between nut size and fertilization. The influence of fertilizer on nut size, if operative at all, was insignificant.

SUMMARY AND CONCLUSIONS

Individual production records were obtained on 490 coconut palms producing 145,850 nuts in the course of the experiments. The palms were in three different localities, and each group represented a distinct stage in the life of the tree. The production record on the youngest palms extended to 15 years after planting and for the older groups through more than 6 and 11 years, respectively. The data collected furnish information on the bearing habits of the coconut palm, which should be of value wherever the coconut is grown.

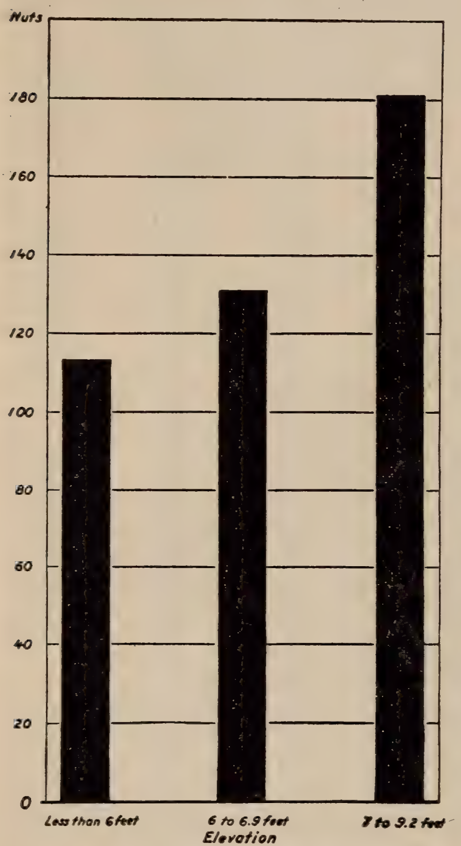

FIGURE 13.—Average production per palm in 40 harvests at Boquillas plantation, palms grouped according to elevation above sea level

The palms in the youngest group appeared to have benefited from fertilization inasmuch as all the treated plats considerably surpassed the untreated plat in production. However, in view of the contradictions displayed in the other plats, and also of the existence of but a single check plat, it may be questioned whether the inferiority of the latter was due mainly to the lack of fertilization or to an aggregation of naturally low-yielding palms within it. The results from plats fertilized with nitrogen, phosphoric acid, and potash in combinations of two or more elements were so contradictory as to lead to the conclusion that the differences between plats resulted principally from factors other than fertilizer treatment. It is illogical to assume that the application of nitrogen and phosphoric acid, the fertilizer treatment given to the most productive plat, resulted in significant increases when similar and even twice the amounts of nitrogen and phosphoric acid in combination with potash gave increases only a little more than half as great.

In the fertilizer tests with palms of intermediate age the yield of low-production palms increased decidedly under fertilization, whereas high-production palms showed little change in productivity.

The inconsistencies presented by the production record were such as to warrant no conclusions in regard to the favorable effect of any particular treatment.

The tests with the oldest palms, conducted on a larger scale than with the younger trees, presented much the same contradictions in regard to effects of nitrogen, phosphoric acid, and potash on production. Pronounced inequalities in productivity were shown which were geographical, since they were related to the location of the palms in the field and unrelated to the fertilizer treatment.

No correlation between nut size and fertilization was shown to exist. Average diameters of nuts from each of seven plats receiving

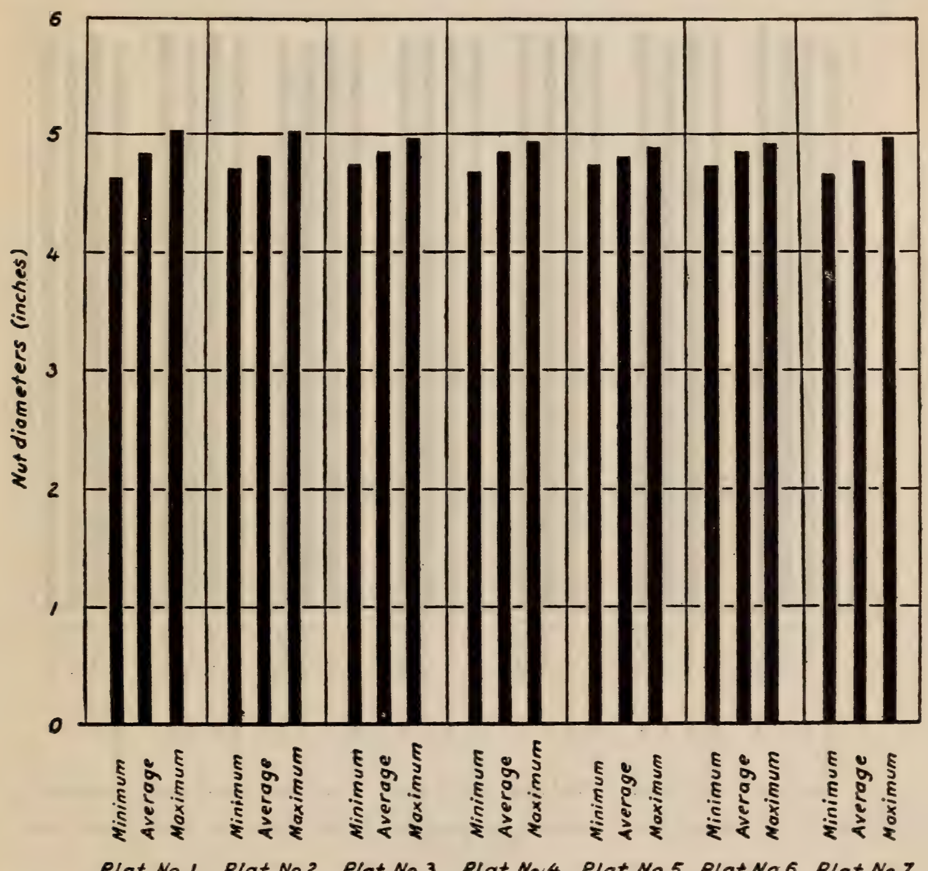

FIGURE 14.—Minimum, average, and maximum nut diameters of lots of 100 nuts, first to twentieth harvest, inclusive, Boquillas plantation

different fertilizer treatments differed by 1 per cent and less, as was shown by the measurements of 14,000 nuts.

Salt (NaCl) was applied to palms in each of the three groups. In the youngest palms the salted plat produced particularly well and contained a larger number of highly productive palms than did any other plat. Also the early results of salting on a larger scale were promising, but the trees were destroyed by hurricane before yielding conclusive evidence. In palms of intermediate age, the application of salt in conjunction with nitrogen and phosphoric acid resulted in no apparent benefit. Following the termination of the experiments with the commonly used fertilizers on the older palms, salt was applied, but without any observed effect on production. Salted and check plats alike showed a decline in production which was notable principally for uniformity.

These results do not justify the recommendation of any particular element or combination as a fertilizer for coconuts. The most striking thing about the results is their inconsistency. In seeking for a more satisfactory answer to the question of fertilization of coconut palms, fertilizer experiments should be made with a much larger number of trees than were used in this case, and in replicate, in view of the pronounced variation in productivity between indi-

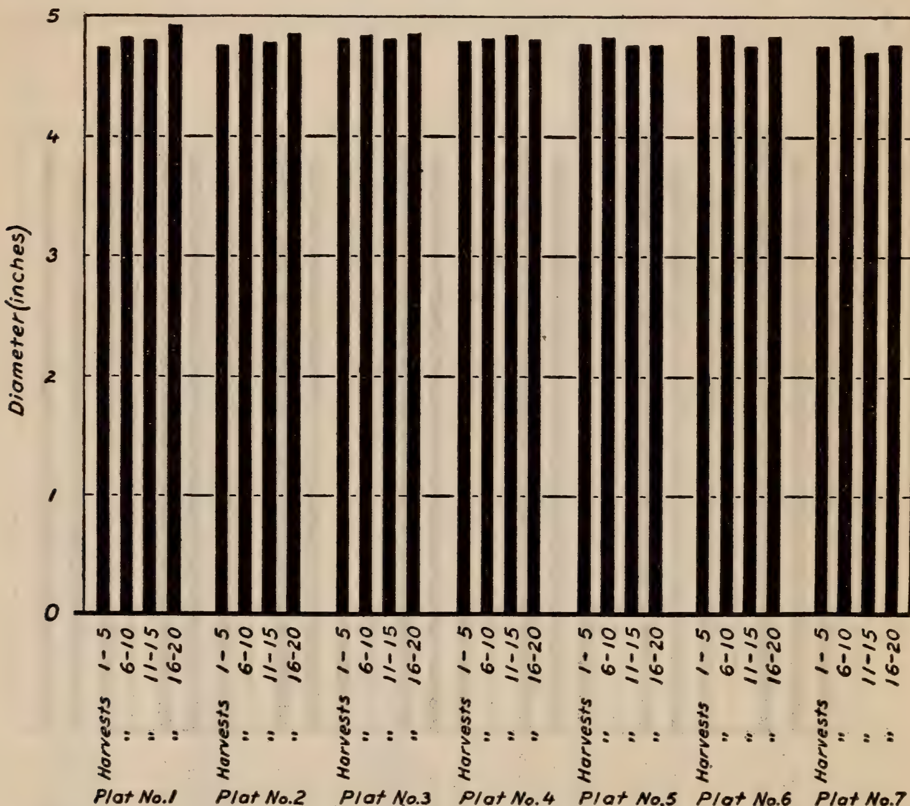

FIGURE 15.—Average nut diameters by periods of five harvests each, Boquillas plantation

vidual palms and the impossibility of securing uniformity through asexual propagation.

The study of production in relation to elevation of palms grown at 4.2 to 9.2 feet above sea level showed that the better drainage afforded by higher elevation was an important factor in the promotion of heavier production. Adequate drainage ditches would presumably greatly increase production in many plantations, as the low-lying littoral usually planted to coconuts is often very poorly drained. General soil-improvement practices, such as providing drainage and supplying humus through the growing of leguminous cover crops, may accomplish far more than applications of fertilizers and at a smaller cost.

The important fact clearly brought out by the data was the wide variation in production between individual palms. This held true even for palms of the same age, receiving the same cultural and fertilizer treatment, and grown under apparently very uniform soil conditions. Such differences could be ascribed only to inherent differences in the palms themselves.

Ten palms produced three times as many nuts as were produced by 10 others in the youngest group of palms. Twenty-five palms, somewhat more than one-quarter of the group, produced more than twice as many nuts as were produced by 25 other palms. In the intermediate-age group, 25 palms, one quarter of the group, produced nearly three times as many nuts as were produced by another quarter. In the older group, the 50 most productive palms, constituting one-sixth of the whole, produced 4.7 times as many nuts as were produced by the 50 least productive palms.

In the youngest group, although no highly productive palms were found in the untreated plat, the distribution of palms of low and high yield through the other plats was such as to indicate that the wide variation in individual productivity was due mainly to some factor far more potent than the fertilizer treatment. In the older groups the distribution among the plats of the high and low yielding palms showed a tendency to produce much or little unrelated to the kind of fertilizer applied. In the intermediate-age group, although the low-production palms showed a decided increase in yield under fertilization, in contrast with the absence of any similar response to fertilization on the part of the high-production palms, the former continued to maintain their relative positions as low yielders in comparison with the other palms. Fertilization as employed in the experiments failed to transform low-production palms into palms of high production.

The tendency to produce much or little becomes evident early in the life of the palm. The high yielders are likely to mature early and so come into production ahead of the low yielders. A long record is unnecessary for a comparative classification of palms as to productivity. Production recorded through several years should suffice for a general classification, and extremes of high and low production should be indicated in an even briefer period.

The pronounced, inherent differences in productivity between palms indicate the line along which lies the greatest promise of improvement in coconut production. No longer should any chance nut whatever serve for planting. Nor should the selection of seed nuts from the best palms be sufficient. The flowers from which such nuts developed may easily have been fertilized by pollen from the poorest drone tree in the plantation. Nature has provided against self-fertilization in the coconut. Man should see to it that for propagation purposes only the best palms, considered in respect to both quality and quantity production, serve as pollen parents and mother plants, so that each nut planted may be of pedigreed stock and carry a double inheritance of desirable characteristics. The results would repay the effort manyfold.

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